

**AAPG European Region Annual Conference**  
**Paris-Malmaison, France**  
**Short Course**  
**21 November 2009**

**GEOLOGICAL HISTORY of CO<sub>2</sub>:**  
**CARBON CYCLE and NATURAL SEQUESTRATION of CO<sub>2</sub>**

Alain-Yves Huc  
Institut Français du Pétrole

With respect to the current genuine public concern regarding the anthropogenic increase of greenhouse gases, a great deal of research and technology development focuses on the capture and underground storage of industrial quantities of CO<sub>2</sub> concentrated in emissions from combustion sources, such as power plants and other industrial activities. However at the global scale the largest sink for the CO<sub>2</sub>, diluted within the atmosphere relies on natural biogeological processes. In this respect the understanding of the fate of the exospheric CO<sub>2</sub> (atmosphere and hydrosphere) requires a sound knowledge of the involved factors in the modern terrestrial eco-system and benefits from the geological perspective which provides the unique opportunity to investigate these processes, their consequences and their kinetics at different time scales.

During Earth's history the atmospheric CO<sub>2</sub> has been subjected to extensive changes in term of absolute quantity and relative concentration. At the geological scale, the current anthropogenic driven alteration of the Earth's atmosphere is actually embedded within a period of very low concentration of atmospheric CO<sub>2</sub> ("Ice House") initiated few ten millions years ago. A situation which is similar to the one prevailing during the other major glaciation periods (Late Carboniferous-Early Permian and Neoproterozoic). The remaining time intervals of the Phanerozoic were apparently dominated by "Green House" conditions. A situation resulting from the very high concentration of atmospheric CO<sub>2</sub>, due to volcanic and metamorphic degassing associated with the long term tectonic activity of the Paleozoic and Mesozoic megacycles. The subsequent decrease of atmospheric CO<sub>2</sub> at the end of the megacycles is interpreted by a negative feedback involving the CO<sub>2</sub> driven silicate weathering which consumes CO<sub>2</sub>. Other models emphasise the major role of accelerated erosion as a consequence of continents configuration and geomorphology patterns controlled by plate tectonic activity and mountain building. The time scale associated with the return to a low level of atmospheric CO<sub>2</sub> is usually taken in the order of few 10 Ma. Based on the CO<sub>2</sub> sourcing (tectonic degassing) and CO<sub>2</sub> sinking (sedimentation of carbonates and organic matter), constrained by isotopic and sediments mass balance considerations, the most popular model depicting the change of atmospheric CO<sub>2</sub> during the Phanerozoic is the 1D Berner's model.

The resulting curve which exhibits the long-term change is, to some extent, comforted by the comparison with the estimates of past PCO<sub>2</sub> values provided by different indicative proxies. However it should be kept in mind that this record is discontinuous and needs to be complemented by a larger data base. Moreover some available data depart from the model and high resolution series of proxies suggest that high amplitude and high frequency changes in atmospheric CO<sub>2</sub> were occurring at a much lower time scale than the one predicted by the smooth curve of the Berner's model, which consequently has to be taken as a 1<sup>st</sup> order scale simulation of the atmosphere composition. Implications include the possibility to better explain short term climatic events such as the Late Ordovician continental-wide glaciation, to reconsider the significance of brutal events of injection of CO<sub>2</sub> in the atmosphere as a result

of intra-plate volcanism and associated metamorphism, and their environmental responses and geochemical record in oceanic sediments (i.e. the Siberian and Dekkan trapps), to revisit the so-called climatic optima such as the Late Paleocene and Early Eocene, and the necessity to improve our assessment of the kinetics of the retroaction loops controlling the level of CO<sub>2</sub> in the atmosphere.

Together with the needed development of very high resolution geochemistry, the recent advent of geographic models coupling climate and biogeochemistry provides powerful tools to investigate the kinetics of the involved processes at the pertinent space and time scales.

The main reservoir of carbon is the Mantle. It is likely the repository of a large part of the CO<sub>2</sub> which was initially present in the primitive atmosphere of the Earth, following accretion and degassing, and from which it was probably progressively withdrawn through the process of subduction. The two other major reservoirs of carbon are the sedimentary carbonates and organic matter. The progressive build up of these reservoirs correspond to a long-term sink for around 80 bar of atmospheric CO<sub>2</sub>. It should be noted that for both of them the processes involved in the transformation of CO<sub>2</sub> into carbonates and kerogen are mainly biologically driven and that the efficiency of these processes tends to increase as biological evolution proceeds. Carbonate producing organisms shifted from passive precipitation to enzymatically controlled precipitation of stromatolithes subsequently evolving from reef construction and shell formation restricted on continental margins to pelagic carbonate plankton. On continents, where the effective sink of CO<sub>2</sub> is the weathering of silicate rocks, the advent of land plants progressively acquiring vascular tissues and roots promoted efficient chemical alteration of minerals and formation of soils. The further rise of flower plants allowing the colonisation of inland settings has extended this impact over the whole continental areas. Following the Precambrian era organisms started to synthesise organic biopolymers resistant to degradation and prone to be fossilised. As an example the lignin appearing during the Carboniferous played a significant role in the preservation of huge amount of coal.